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A VARIABLE SPEED FAN DYNOMOMETER.

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The following Technical Note descriptive of a Variable Speed Fan Dynamometer, was prepared under the supervision of the Automotive Power Plant Section of the Bureau of Standards, and submitted through the Subcommittee on Power Plants for Aircraft to the National Advisory Committee for Aeronautics for publication.

Fan brakes are widely used as absorption dynamometers in testing internal combustion engines because they are comparatively simple, inexpensive, and flexible. They have, however, the disadvantage that a given fan will run at only one speed when the engine is delivering full power, that speed being determined by the size, proportions, and environment of the fan, and the density of the air. In order to be able to vary the speed at which a given power will be absorbed, English manufacturers have for some time been using a cylindrical housing around the fan with one or two variable openings in the periphery. The tests here reported were undertaken by the Automotive Power Plant Section of the Bureau of Standards to determine how great a range of speed can be obtained with such a device. The tests made show that a power ratio of 5 to 1 can be obtained, power ratio being defined as the ratio of the power absorbed by the fan at a given speed with the outlet open to the power absorbed at the same speed with the outlet closed. Since the power absorbed by the fan varies as the cube of the speed at which it runs, the speed ratio (defined similarly to power ratio) obtainable with such a fan is $\sqrt[3]{5}$ or 1.7. The data show that improvements in the design of the fan brake can make the speed ratio approach but not exceed a value of 2 to 1. The meaning of the terms power ratio and speed ratio is more clearly seen from the diagrams.

Data of the B. F. Sturtevant Company show that the power ratio of a centrifugal blower, which is essentially the same as a fan brake, is independent of the speed and size of the blower, depending only upon its shape and proportions, and it is supposed that this is also true of fan brakes.

A brief outline of previous work on fan brakes, description of the experimental apparatus and methods used in the tests, and a more detailed statement of results are given below.

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It has often been shown experimentally that for a given fan brake, the relation of power (hp) to speed (N) is expressed by an equation of the form

$$hp = kN^{3.0}$$

The constant k in this equation depends upon the size, proportion, and environment of the fan and the density of the air. In order to obtain another desired relation of speed to horsepower, one or more of the quantities controlling the constant k must be varied. Control of air density involves such elaborate apparatus as to be discarded at once. Control of size of fan generally necessitates stopping the engine in order to get a different constant, yet this method is used to a considerable extent in commercial engine testing in spite of its inconvenience, as in the Franklin Fan Dynamometer, specifications and calibrations for which are given in the S.A.E. Handbook, Vol. II, p. 45. It is possible to design a device which will change the diameter of the fan blades or the angle at which they strike the air without stopping the engine, but such a device is necessarily rather complex, and may be found unsuited to high-speed work. Fans of this type are, nevertheless, used by several French engine manufacturers. By elimination, it is seen that the control of fan environment is the simplest and easiest method of controlling the horsepower-speed relation of the fan. Morgan and Wood (see bibliography, item 6) give some data on the influence of the environment of a fan on its horsepower-speed relation. They give diagrams showing the effect of a wall in the vicinity of a fan and the effect of putting a square box around the fan. Concerning reproducibility of results, they point out that ordinary weather changes may affect the power absorbed by the fan by as much as 20%, and express the opinion that a fan brake is of little use in exact scientific tests unless some means of measuring the torque is used in conjunction with it.

Although English manufacturers have long been using the method of altering the environment, they are not known to have published any information showing the range of speed control available. Hence, these experiments were undertaken with a view to answering the following two questions:

(1). What range of speed control is obtainable with a fan brake?
(2). Given the rated horsepower and speed of an engine, what is the diameter of fan brake necessary in order to obtain complete tests of power vs. speed?

The general procedure of the experimental work was to mount a two-bladed paddle-wheel fan on a small electric dynamometer, build a cylindrical housing around it, the inlet and outlet of which were of controllable area, and measure simultaneous values of speed and horsepower with different sizes of inlet and outlet. This gave sufficient data to determine the speed and power ratios obtainable by opening and closing the outlet, and the size of inlet for maximum speed control.

The fan consisted of two square pieces of 3 mm (1/8") sheet aluminum about 28 cm (11") on each side, bolted to a steel arm 10 mm x 76 mm (3/8" x 3") by means of steel angles. The diameter of the fan measured from tip to tip of the blades (the nominal diameter) was 1.1 meters (44"). The proportions of the fan brake are shown in Fig. 1, which is a section through the fan blades looking toward the inlet end of the brake. The two ends of the housing were sawed out of slabs of cleated tongue and groove pin and a 45 cm (18") strip of galvanized iron nailed around the periphery of the ends completed the fan brake except for the sliding shutter. The estimated maximum cost of such a fan brake in January, 1920, labor included, is $25.00.

The fan brake was mounted on a 50 horsepower Sprague electric dynamometer. Data for horsepower-speed curves were taken with inlet diameters of 66 cm, 50 cm and 40 cm (26, 20 and 16 inches) respectively, and with inlet closed, the circumferential outlet opening being changed by steps of 2 inches up to 30 inches (76 cm) open for each setting of the inlet. The outlet uncovered about 75° of the periphery of the housing when the circumferential opening was 76 cm (30 inches). Readings of static air pressure in the housing and air velocity through the outlet were also taken with a view to establishing a reasonable basis for the computation of the horsepower necessary to drive a fan brake of different proportions from the one tested, but no satisfactory formulas were obtained.

Plot 2 shows the experimental horsepower-speed curves for the fan brake tested, plotted on the same sheet with a horsepower-speed curve of the fan in free air and curves of several well-known motors. The observed points are shown in circles and dotted lines indicate extrapolation. The slope of the lines is 3.0; this differs from some other observers' results by as much as 0.1. The horizontal distance between curves B and C, measured with a logarithmic scale, is the speed ratio of the fan brake. For the brake tested the speed ratio was 1.7. The horizontal distance between curves A and C gives the maximum speed ratio that could be obtained by any improvements in the design of the fan brake. It will be noticed that A cuts the 1000 r.p.m. line at about the same horsepower that C cuts the 2000 r.p.m. line, so the maximum speed ratio obtainable is 2 to 1. The vertical distance between the two lines gives the power ratio of the fan brake, and is naturally the cube of the speed ratio, or 5 to 1. Since the lines are parallel, the speed ratio is independent of the speed at which the fan is run. This means, of course, that the speed <u>range</u> is greater at higher speeds. At 300 hp, a speed range of 1600 r.p.m. is available, which is more than enough to take a complete full-throttle run on a 300 hp Hispano-Suiza engine. At 18 hp, a speed range of only 650 r.p.m. is available, and this is not quite as great a speed range as is usually used in running tests on Ford motors. Curve D is a typical full-throttle Ford motor curve. While the characteristics of a fan brake give it greater speed range at high speed than at low, it must be very carefully built in order to be run with safety over 1500 r.p.m. Plot 3 shows in heavy lines the curves of horsepower at 1000 r.p.m. against fan diameter for Sturtevant Steel Plate blowers plotted from data given in their catalogue No. 234. These curves indicate that for fans of different diameter having other dimensions proportional to the diameters, the power absorbed by the fan varies about as the fifth power of the diameter, since the slopes of the curves are 5.3 and 5.1 respectively. The fact that the lines for Sturtevant blowers open and closed are parallel, shows that the speed and power ratios are independent of size of fan, and it is assumed for the purposes of this work that this is also true for fan brakes. The dotted lines are for the type of fan brake shown in Fig. 1. Each is drawn through one observed point with a slope of 5 to 1. They can be used to determine the size of fan required to run a test on a given engine provided an approximate horsepower-speed curve for the engine is known, but a fan built with the nominal diameter indicated on the curve may absorb as much as 10% <u>more</u> or 10% <u>less</u> power than indicated on the curve.

Plot 4 shows how the diameter of the inlet affects the power absorbed by the fan and the speed ratio. Curve H shows that the power absorbed by the fan with outlet open varies nearly directly as the inlet diameter, and curve G shows that the power absorbed with the outlet closed remains constant until the inlet diameter becomes greater than the inside diameter of the blades, when it increases. The ratio of any two ordinates on the curve gives the power ratio, which is the cube of the speed ratio, and the speed ratio is plotted as curve K to the same numerical scale as the horsepower curves. Curve K shows that if the diameter of inlet is rD (where D is fan diameter), the best value for r is about 1/2, which makes the inlet diameter just equal to the inside diameter of the fan blades. It might be possible to get a greater speed ratio if the blades were made oblong instead of square, with the axial length greater than the radial depth.

Theoretical and mathematical consideration, which need not be explained here in detail, have been developed to show:

(1) $hp = kN^3D^5$ with proportional dimensions.

(2). In the empirical equation for head resistance in rectilinear air flow, $F = kuSv^2$, where F = force of head resistance, u = density of air, S = area exposed to air flow, and v = air velocity, the constant k for these tests, assuming the resisting torque of the fan to be due only to the air resistance of the flat plate fan blades, agrees within 20% with Eiffel's value as corrected by Duchemin.

(3) In the empirical equation for skin friction in rectilinear air flow, $F = kuSv^2$, where F = force of skin friction and the other symbols are the same as before, the constant k was calculated from the runs with the fan outlet closed on the assumption that the entire resistance to the motion of the fan was due to the skin friction of the cylinder of air on the housing. This constant was of the same order of magnitude as that given by Zahm for rectilinear air flow past a smooth board.

(4) Equations are given in items 4, 5, and 6 of the bibliography for predetermining the performance of fans from their dimensions. While each of these equations was probably true for the particular conditions under which the tests were made, it has already been pointed out that no equation which does not

consider air density and fan environment as well as fan dimensions can be generally true within less than 20%.

The conclusions of this investigation are, briefly:

(1) A fan brake can be made to give a power ratio of 5 to 1 or speed ratio of 1.7 to 1, by means of a variable shuttered housing.

(2) Performance of a fan brake of the same proportions as the one tested but of different diameter can be predetermined to about 20% (ie. $\pm$ 10% from nominal) by means of the curves given. For accurate work a means of measuring torque must be used in conjunction with the fan brake.

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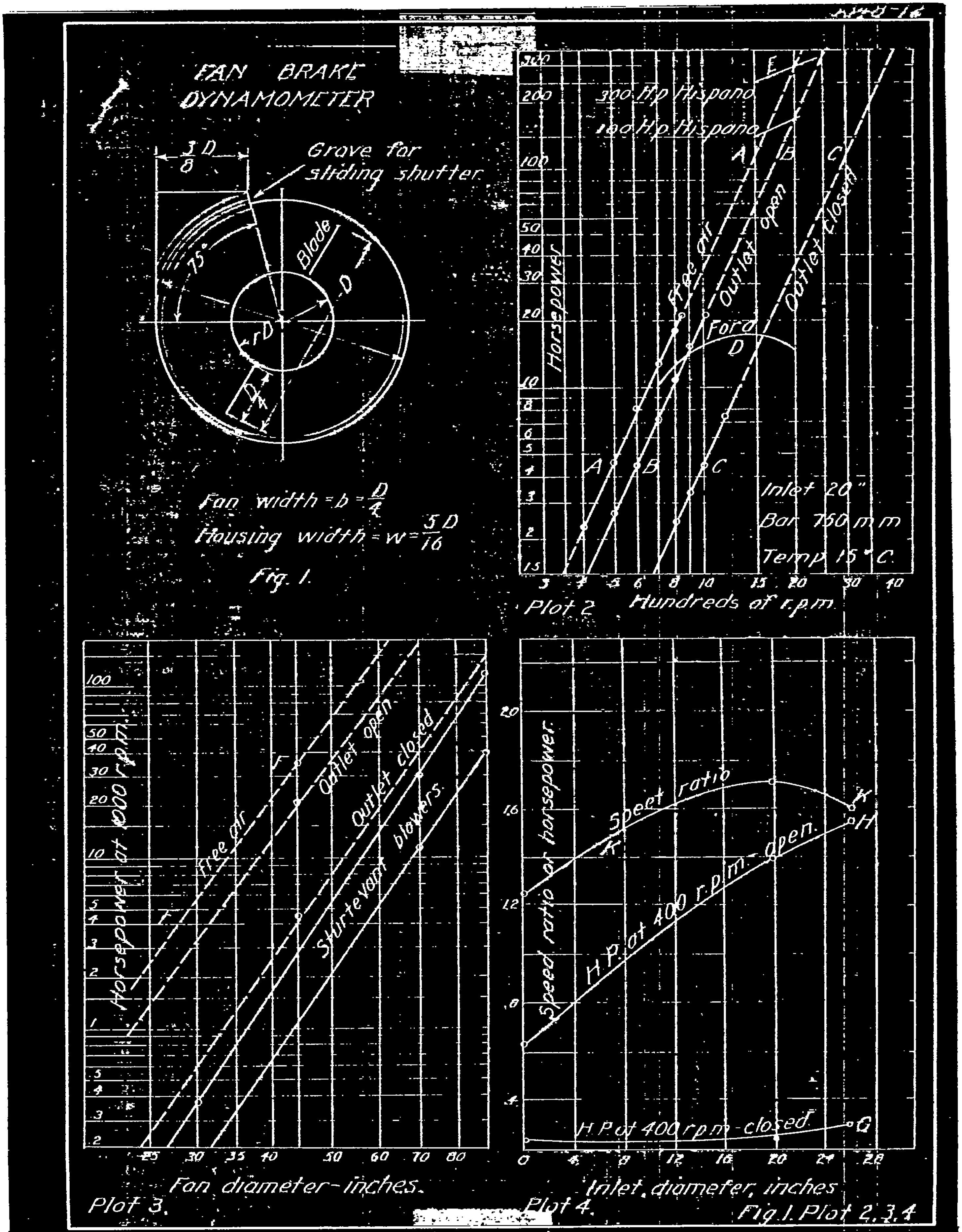

Fig. 1. Plot 2, 3, 4